The University of Chicago

A STUDY OF STELLAR SPECTRA IN THE REGION 6562 A–7593 A

A PART OF A DISSERTATION SUBMITTED TO THE FACULTY OF THE DIVISION OF THE PHYSICAL SCIENCES IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS

1934

By

FRANKLIN EVANS ROACH

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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 80 NOVEMBER 1934 NUMBER 4

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By F. E. ROACH

ABSTRACT

On grating spectrograms of Procyon, Arcturus, Aldebaran, and Betelgeuze, 426 stellar lines have been measured in the region between $H\alpha$ and the head of the atmospheric A band. Satisfactory identifications of a large number of the lines have been made.

In Vega and Sirius this part of the spectrum has 33 lines, most of which are not strong.

Radial velocities deduced from the measures of the first group of stars are found to agree with the values obtained for the ordinary spectral region.

Lines of the following elements are definitely present: *H*, *Al*, *Si*, *S*, *Ca*, *Ti*, *V*, *Cr*, *Fe*, *Zr*.

The unblended lines of neutral silicon are weakened appreciably in the cooler stars.

Three lines of neutral sulphur are found in Procyon, strengthening the case for this element in the sun.

Titanium is represented by 29 lines, of which 17 are probably unblended. They are prominent in the red stars. *TiO* bands of the red infra-red system are very strong in Betelgeuze and moderately so in Aldebaran.

Iron contributes to about 150 stellar lines in this region. In the cooler stars the low excitation lines are enhanced relative to those of high excitation potential. In Procyon the converse is true.

Twenty-four lines are attributed to neutral zirconium.

With the development of improved emulsions for the red and near infra-red it is possible to extend to longer wave-lengths our knowledge of stellar spectra. In three papers P. W. Merrill and O. C. Wilson, Jr.,[1] have discussed their investigations covering chiefly the region to the red of the terrestrial A band. The purpose of the present study is to fill the gap between the spectral region available with the panchromatic emulsions and that covered by Merrill.

[1] *Ap. J.*, **74**, 188, 1931; *Mt. W. Contr.*, No. 432; *Ap. J.*, **79**, 183, 1934; *Mt. W. Contr.*, No. 486; *Ap. J.*, **80**, 19, 1934; *Mt. W. Contr.*, No. 494.

OBSERVATIONAL MATERIAL

The twenty spectrograms used in this investigation were taken with the Yerkes auto-collimating grating spectrograph attached to the 69-inch reflector of the Perkins Observatory. Eastman emul-

TABLE I

LIST OF SPECTROGRAMS MEASURED

Star	Date (U.T.)	Exp. Time Minutes	Radial Velocity	No. of Lines*	Velocity†
α' Ori	1933 Nov. 20.3‡	60	+18.9	7	+21.0
	Dec. 23.3	70	+18.8	9	.....
	1934 Feb. 10.1	230	+21.3	18	.....
	Mar. 7.1	210	+21.0	17	.....
α Tau	1933 Oct. 14.3	60	+50.4	8	+54.1
	1934 Jan. 22.0	196	+53.2	23	.....
	Jan. 27.2	240	+52.7	13	.....
α Boo	1933 June 6.2	140	− 3.9	53	− 5.1
	June 15.1	90	− 2.5	42	.....
	1934 Apr. 9.2	154	− 3.0	13	.....
	Apr. 10.2	30	− 7.0	35	.....
	May 31.2	150	− 2.2	36	.....
α CMi	Mar. 29.1	166	− 9.1	9	− 4.3§
	Apr. 9.1	160	− 7.5	15	.....
	Apr. 10.0	88	− 4.7	25	.....
	Apr. 10.1	62	−10.8	18	.....
α CMa	Jan. 21.1	180	.....	.....	.....
α Lyr	1933 July 17.2	201	.....	.....	.....
	July 18.2	320	.....	.....	.....
	1934 Apr. 10.4	90	.....	.....	.....

* Number of lines used in radial velocity determination.

† *Lick Obs. Pub.*, **18**, 1932.

‡ This plate is one belonging to the Perkins Observatory and loaned to the writer by Dr. Bobrovnikoff.

§ Velocity of Procyon computed from formula in *Trans. I.A.U.*, **3**, 175, 1928.

sions IV-N, III-U, and IV-U were used, chiefly IV-N. All plates were hypersensitized in a 4 per cent ammonia solution. Development was with Eastman D-11.

In Table I are the data concerning the spectrograms. The second plate of α Orionis and the first of α Tauri are strong exposures on panchromatic (Eastman III-F) emulsion, which extend somewhat to the red of *Hα*.

The measures were made with the small Gaertner measuring machine of the Perkins Observatory. The comparison spectrum is from a neon lamp, giving 16 lines over this region. The linear dispersion varies from about 26.6 A per millimeter at *Hα* to 26.4 A per millimeter at 7500 A. The slight departure from normality justifies the use of a parabolic interpolation formula for the reduction of the measures to wave-lengths. The probable error of a single wave-length determination from one plate is ±0.08 A.

INTENSITY SCALE OF LINES

Each line was given an estimate of intensity at the time of measurement, from 0 for a line whose reality is doubtful to 10 for a very

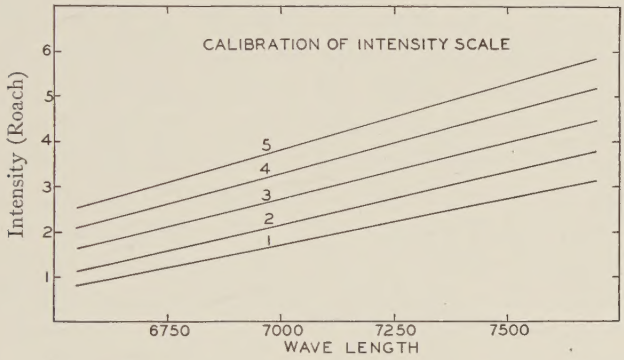

FIG. 1.—The straight lines indicate the intensities of the *Revised Rowland*

strong line. In order to evaluate my scale it has been compared with that of the *Revised Rowland*[2] for this region, using solar plates taken under the same instrumental conditions as were the stellar spectrograms. Figure 1 indicates the nature of the relationship. Near *Hα* a line of intensity 1 on the Rowland scale is just visible on my plates, while at 7500 A a line of Rowland intensity 1 is about 3 on my scale.

It is of interest to note that the same change in the *Revised Rowland* scale has been observed by G. F. W. Mulders.[3] He ascribes the variation to a change with wave-length in the gradation of the plates on which the original Rowland measures were made.

[2] St. John, Moore, Ware, Adams, and Babcock, *Revision of Rowland's Preliminary Table of Solar Spectrum Wave-Lengths*, 1928.

[3] *Zs. f. Ap.*, **8**, 62, 1934.

RADIAL VELOCITIES

The radial velocities are recorded in Table I. Attention is called to a range of 6 km/sec. in the velocity of Procyon (the probable errors are ±0.6 and ±1.0 km/sec. for plates 315 and 316). The material is insufficient to establish this variation. For Arcturus the range is 5 km/sec.

LINES OF TERRESTRIAL ORIGIN

The presence of a large number of telluric lines in this spectral region complicates the identification of the stellar lines. Table II

TABLE II

LINES OF TERRESTRIAL ORIGIN

Wave-Length	Int.	Source	Wave-Length	Int.	Source	Wave-Length	Int.	Source
6867.235..	20	*O*	6986.592..	2	wv	7236.150..	1	Atm
6869.96...	0	*O*	6989.001..	2	wv	7240.578..	7	Atm
6871.147..	2	*O*	6990.391..	1	wv	7243.645..	3	Atm
6872.558..	2	*O*	6993.731..	3	wv	7245.690..	3	Atm
6874.716..	2	*O*	6998.981..	4	wv	7247.224..	2	Atm
6877.188..	2	*O*	7004.766..	4	wv	7250.230..	0	Atm
6879.350..	2	*O*	7011.342..	1	wv *Fe*	7252.938..	8	Atm
6883.844..	3	*O*	7016.452..	5	wv	7257.952..	4	Atm
6886.283..	5d	*O*	7019.368..	0	Atm	7267.011..	1	.....
6889.456..	7d	*O*	7023.517..	2	Atm wv	7265.324..	5	Atm
6892.869..	6d	*O*	7027.491..	4	Atm—	7270.....	3	.....
6896.530..	6d	*O*	7037.555..	3	Atm	7272.987..	4	Atm
6900.441..	5d	*O*	7039.807..	3	Atm	7275.411..	2	Atm
6904.581..	5d	*O*	7167.918..	4	Atm	7277.405..	3	Atm
6908.997..	5d	*O*	7170.580..	4	Atm	7287.643..	4	Atm
6913.661..	5d	*O*	7173.191..	5	Atm	7290.426..	6	Atm
6918.576..	5d	*O*	7176.064..	1	Atm	7292.444..	1	Atm
6923.753..	4d	*O*	7177.506..	5	Atm	7295.047..	2	Atm *Fe*
6929.179..	3d	*O*	7181.614..	4	Atm	7299.937..	3	Atm
6933.730..	3	*Fe*, *O*, wv	7184.472..	3	Atm	7303.799..	5	Atm
6934.867..			7186.719..	5	Atm	7309.279..	5	Atm
6937.901..	1	wv	7191.692..	5	Atm	7312.632..	2	Atm
6940.008..	2	wv, *O*	7193.672..	3	Atm	7315.530..	1	Atm
6941.987..	1	wv, wv	7195.052..	1	Atm	7317.310..	1	Atm
6943.815..	1	wv	7198.001..	4	Atm	7318.707..	3	Atm
6947.552..	3	wv	7200.775..	6	Atm	7323.986..	2	Atm
6949.032..	2	wv	7204.185..	3	Atm	7327.388..	2	Atm
6950.774..	2	wv	7206.433..	4	Atm	7330.876..	2	Atm
6953.586..	3	wv	7209.513..	2	*Ti* Atm	7333.683..	4	Atm
6956.433..	4	wv	7216.541..	3	Atm	7335.334..	0	Atm
6959.467..	2½	wv	7223.652..	4	Atm *Fe*	7349.490..	3	Atm
6961.275..	3	wv	7227.507..	3	Atm	7369.208..	2	Atm
6964.564..	0	wv	7232.749..	5	Atm	7383.722..	3	Atm
6977.487..	2	wv	7234.750..	5	Atm	7593.699.....	.....	.....
6981.474..	2	wv						

lists the atmospheric lines, which are based on the following criteria: (1) inclusion in the *Revised Rowland;* (2) absence of radial velocity shift; (3) presence in stars of all spectral classes considered in this paper, namely, Ao–M2. The wave-lengths are from the *Revised Rowland* and represent the weighted mean when two or more lines are blended on my plates. Intensities are on my scale. The letter "d" in the intensity column indicates that the line is just visibly double. The data for the source columns are from the *Revised Rowland.*

LINES IN FOUR STARS, 6562–7593 A

In Table III the results of the wave-length determinations in Betelgeuze, Aldebaran, Arcturus, and Procyon are summarized. In the first column are the observed wave-lengths. The second, third, fourth, and fifth columns record the measured wave-lengths, followed by the estimated intensities of the lines in the respective stars. Columns 6–8 give the suggested identifications. In column 7 are the wave-lengths taken from the *Revised Rowland,* wherever possible, followed by the laboratory intensities. Wherever the *Revised Rowland* wave-lengths are not employed, the recorded value is in italics. The excitation potentials in volts are given in column 8. The data for the solar intensities in disk and spot are from the *Revised Rowland,* with the exception of a few of the disk intensities of lines beyond about 7300 A, which are taken from Meggers.[4] In the last column an estimate has been made of the extent to which the laboratory line contributes to the observed stellar line. "A" denotes a principal contributor; "B," an important contributor; "C," a minor contributor; and no letter indicates a slight or doubtful contributor.

LINES IN VEGA AND SIRIUS

Because lines due to the ionized elements tend to lie in the photographic region of the spectrum, it is not surprising that only a few lines have been found in these A-type stars. Of the 33 stellar lines recorded in Table IV, only one is identified with certainty, namely, *Hα.* The line at 7389.5 A is identified provisionally with *Fe* 7389.39. Six other coincidences with high excitation iron lines are noted.

[4] *Pub. of the Allegheny Obs.,* **6,** 13, 1929.

TABLE III

Absorption Lines in Four Stars, 6562–7593 A

Wave-Length Obs.	Betel-geuze	Alde-baran	Arc-turus	Pro-cyon	Identification				Sun		Con-trib-utor
					El.	W.-L.	Int.	E.P.	Dk.	Sp.	
6562	2.64	2.74	2.89	2.80	*H*	2.82	....	10.2	40	20	A
6565	.....	5.85 2	5.92 1	.....	*V?*	5.85	2	1.2	— 3	— 1?	.....
6566	6.62 2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6569	9.31 2	9.31 2	9.13 2	9.24 1	*Fe*	9.23	5	4.7	4	3	A
6570	.....	.....	0.53 1	.....	*Mn*	*0.79*	....	....	.....	.....	.....
6572	2.81 3	2.76 3	2.42 2	.....	*Ca*	2.80	8	0.0	1	6	A
					Cr	*2.89*	2	1.0	.....	.....	.....
					Fe	4.24	2	1.0	1	3	B
6574	4.68 3	4.75 3	4.75 3	4.87 1	*Fe*	5.05	2	2.6	2	2	B
					Ti	5.19	3	2.6	.....	— 1	.....
					⊙	6.60	....	....	.....	— 2	.....
6576	6.7 0	6.52 1	7.07 1	.....	*Ni*	6.91	pr	5.3	— 3	.....	.....
					V	8.97	....	1.0	.....	— 2	.....
6578	8.6 0	8.84	.....	.....	⊙	9.09	....	....	.....	— 2	.....
					Cr	*0.91*	1	1.0	.....	— 1	B
6581	1.08 3	1.07 3	1.09 3	.....	*Fe*	1.23	2	1.5	0	1	A
6586	6.20 2	6.24 3	6.29 3	.....	*Ni* *Fe*	6.33	6	1.9	1	3	A
6589	.....	9.25 1	.....	.....	.....	.....	.....	.....	.....	.....	.....
6592 6593	3.36 6	3.15 5	2.87 2 3.86 2	3.04 1 3.92 1	*Fe*	2.93	10	2.7	6	7	A
					Fe	3.89	4	2.4	4	7	A
6596	.....	.....	6.24 1	.....	*Co*	5.91	12	3.7	— 2N	.....	.....
6597	.....	7.42 1	.....	.....	*Cr*	7.58	2	4.2	2	1	.....
					Fe	7.58	....	4.8	2	1	.....
6598	8.94 4	8.98 3	8.91 3	9.14 1	*Ni*	8.62	3	4.2	0	— 1	B
					Ti	9.13	12	0.9	— 1	4	A
6600	0.76 1	.....	0.78 1	.....	.....	.....	.....	.....	.....	.....	.....
6601	.....	.....	.....	1.66 1	.....	.....	.....	.....	.....	.....	.....
6602	.....	.....	2.52 1	.....	.....	.....	.....	.....	.....	.....	.....
6603	3.11 1	.....	.....	.....	*Fe?*	3.37	pr	2.4	— 3N	.....	.....
					Zr	*3.27*	8	1.5	.....	.....	C
6604	.....	.....	4.30 1	4.19 1	*Sc+*	4.61	10	1.4	1	0	B
6605	5.56 2	5.82 2	6.09 1	.....	*Mn*	5.58	6	4.4	— 2	1	B
					V	5.93	5	1.2	— 2N	2	A
6607	7.97 1	7.87 1	.....	.....	*V?*	7.90	....	1.3	.....	— 1	B
					Fe	8.05	2	2.3	0	1	A
					Fe	9.13	4	2.5	3	5	A
6609	9.32 3	9.29 3	9.30 3	.....	*FeA*	9.59	1	1.0	— 1	— 1?	.....
					⊙	9.70	.....	.....	— 2	1	C
6612	.....	.....	2.25 1	.....	*Cr*	2.25	3	4.1	— 2	.....	.....
6613	3.85 2	3.77 3	3.78 2	.....	*Fe*	3.82	pr	1.0	— 1d?	1	.....
					V+	3.8	....	1.7	.....	.....	.....
6616	.....	6.57 1	6.44 1	6.95 1	*Co*	7.04	6	4.5	— 2d?	.....	.....
6618	8.68 1	8.54 1	8.81 1	.....	.....	.....	.....	.....	.....	.....	.....
6620	.....	0.56 1	.....	.....	*Zr*	*0.62*	5	2.3	.....	.....	.....
					⊙	1.12	....	....	.....	2	.....
6622	.....	2.69 1	2.06 1	.....	.....	.....	.....	.....	.....	.....	.....
					⊙	4.78	....	....	.....	0	.....
6624	4.94 6N	4.88 4	4.82 3	.....	*V*	4.85	5	1.2	— 3N	1	A
					Fe	5.05	1	1.0	0	2d	B
					TiO	*0.08*	2	....	.....	.....	B*
6627	.....	7.7 0	7.71 1	.....	*Fe*	7.57	3	4.5	1	0	B
6630	9.91 1	0.10 1	9.97 1	.....	*Cr*	0.04	4	1.0	— 2	4	A
6632	1.78 1	.....	2.26 1	.....	*Co?*	2.48	15	2.3	— 1N	— 1	.....
6633	3.78 1	3.72 2	3.73 3	3.51 1	*Fe*	3.77	7	4.5	2	1	A
6634	4.7 3N	.....	.....	.....	*TiO*	*4.30*	2	....	.....	.....	A
6635	6.14 1	.....	5.91 1	.....	.....	.....	.....	.....	.....	.....	.....
6639	9.68 2	9.79 2	9.67 1	.....	*Fe*	9.73	pr	4.6	0	.....	.....
6640	.....	.....	.....	0.32 1	.....	.....	.....	.....	.....	.....	.....
6643	3.63 4	3.72 3	3.54 3	3.45 2	*Ni*	3.65	20	1.7	5	6	A
6646 6648	7.54 2	7.66 2	6.94 1 8.38 1	..... 8.16 1	*Fe*	6.98	1	2.6	— 1	0	A
					Fe?	8.13	pr	1.0	— 2	— 1	.....
6651	1.66 5	1.34 2N	1.59 1	.....	*TiO*	*1.46*	5	....	.....	.....	A*
6653	.....	.....	3.94 1	.....	*Fe?*	3.92	....	4.1	— 1	— 2	.....
6656	.....	6.77 2N	.....	.....	.....	.....	.....	.....	.....	.....	.....
6657	.....	.....	7.24 1	.....	.....	.....	.....	.....	.....	.....	.....

* *TiO* does not contribute to this line in Arcturus.

TABLE III—*Continued*

Wave-length Obs.	Betel-geuze	Alde-baran	Arc-turus	Pro-cyon	Identification				Sun		Con-tribu-tor
					El.	W.-L.	Int.	E.P.	Dk.	Sp.	
6660	.....	0.81 2	0.96 1	.....	*Cb*	*0.76*	150	....	.....	.....	B
					Cr	1.09	12	4.2	— 1	1d	B
6663	3.33 3	3.39 4	3.32 3	3.28 2	*Fe*	3.26	1	4.5	1	0	C
					Fe	3.47	8	2.4	3	4	A
					Ti?	6.55	2	1.5	— 2N	.....	.....
6667	7.32 2N	7.16 3N	7.75 1N	.....	*Fe*	7.46	pr	2.4	— 2	.....	.....
					Fe	7.75	....	....	— 1	.....	.....
6677	7.99 5	8.09 5	7.97 5	7.88 2	*Fe*	8.01	12	2.7	5	5	A
6681	.....	.....	1.39 1	.....	.....	.....	.....	.....	.....	.....	.....
6681	1.62 5N	1.58 2N	.....	.....	*TiO*	*1.06*	6	....	.....	.....	A
6683	.....	.....	3.32 1	.....	.....	.....	.....	.....	.....	.....	.....
6684	.....	.....	4.99 1	.....	*Co*	4.90	5	....	— 3	.....	.....
6685	5.61 1	5.86 2n	.....	.....	*TiO*	*5.97*	1	....	.....	.....	B
6687	.....	8.04 2n	7.81 1	.....	*V*	7.57	25	0.0	.....	0	.....
6689	.....	.....	9.33 1	.....	.....	.....	.....	.....	.....	.....	.....
6696	.....	6.23 2	6.28 2	.....	*Al*	6.04	3	3.1	1N	2	A
					⊙	6.33	....	....	0	.....	B
6698	.....	8.82 1	8.63 1	.....	*Al*	8.68	3	3.1	0	0	A
6701	.....	1.37 1	1.06 1	.....	*Ni?*	0.93	....	4.2	— 3	.....	.....
					⊙	1.39	....	....	— 2	.....	.....
6703	.....	3.63 1	3.49 2	.....	*Fe*	3.59	2	2.7	1	2	A
6705	.....	4.96 1	5.09 1	.....	*Fe*	5.12	....	....	1	0	A
					⊙	7.46	....	....	— 2	.....	.....
6707	.....	7.43 2	7.26 1	.....	*Li*	7.77	....	0.0	.....	2N	.....
					Li	7.94	....	0.0	.....	1N	.....
6710	0.50 2	0.26 2	0.41 2	.....	*Fe*	0.33	1	1.5	0	1	A
6713	.....	.....	3.24 1	.....	*Fe*	3.05	3	4.6	1	ob	B
					Fe	3.75	1	4.8	1	0	B
6715	4.84 5	5.42 1n	.....	.....	*TiO*	*4.37*	6	....	.....	.....	A
6715	.....	.....	5.77 1	.....	*Fe*	5.40	3	4.6	1	1	.....
6717	7.69 4	7.77 3	7.66 4	7.61 2	*Ca*	7.70	30	2.7	5	8	A
6721	.....	.....	1.45 1	.....	.....	.....	.....	.....	.....	.....	.....
6722	.....	2.73 1n	2.19 1	2.23 1	.....	.....	.....	.....	.....	.....	.....
6723	.....	.....	.....	3.98 1	.....	.....	.....	.....	.....	.....	.....
6726	6.15 1	6.16 2n	6.23 2n	.....	*Fe*	6.68	3	4.6	2	1	.....
6728	.....	.....	.....	8.31 1	.....	.....	.....	.....	.....	.....	.....
6728	.....	8.9 0	.....	.....	*Fe*	9.03	....	....	— 1	0	.....
6730	.....	0.4 0	9.9 0	.....	⊙	0.32	....	....	— 2N	.....	.....
6733	.....	.....	3.35 1n	.....	*Fe*	3.16	3	4.6	1	0	B
6734	4.45 1	4.59 1	.....	.....	.....	.....	.....	.....	.....	.....	.....
6737	.....	7.24 1	.....	.....	.....	.....	.....	.....	.....	.....	.....
6739	9.72 3	9.64 2n	9.39 2	.....	*Fe*	9.53	1	1.6	0	1	A
6743	3.27 2	3.17 2	3.13 3	.....	*Ti*	3.14	10	0.9	1	4	A
6743	.....	.....	.....	3.52 1—	*S*	3.58	6	7.8	— 2N	— 2N?	A
					⊙	5.56	....	....	— 2N	2	.....
6745	6.3 0	5.9 1N	6.0 0n	.....	⊙	5.99	....	....	— 1	1	.....
6748	8.04 3n	8.1 1n	.....	.....	*TiO*	*7.80*	5	....	.....	.....	A
6748	.....	.....	.....	8.69 1	*S*	8.79	8	7.8	— 2	.....	A
6750	0.21 2	0.15 2	0.12 2	0.20 1	*Fe*	0.17	6	2.4	3	4	A
					Zr	*2.73*	10	1.0	.....	.....	A
6753	3.22 3	3.00 4	2.94 3	.....	*Fe*	2.73	3	4.6	1	1d	B
					V?	3.02	....	1.1	— 2N	.....	A
6755	6.1 0	6.1 0	5.83 1	.....	*Fe*	5.61	....	....	0	0	C
6757	.....	.....	.....	7.25 1+	*S*	7.20	10	7.8	— 1d	— 1	A
6757	7.9 0	7.6 0	.....	.....	*Cr*	*7.76*	4	....	.....	.....	.....
					Cr	*2.42*	5	....	.....	.....	.....
6762	2.30 1	2.35 2	.....	.....	*Zr*	*2.41*	20	0.0	— 2	.....	.....
6764	.....	4.45 1d	.....	.....	.....	.....	.....	.....	.....	.....	.....
6766	6.98 2n	6.40 3	6.0 0	.....	*V*	*6.53*	3	....	.....	.....	.....
6767		7.74 2	7.85 3	7.66 1	*Ni*	7.79	20	1.8	4	5	A
6771	0.87 1	1.01 2	1.20 2	.....	*Co*	1.07	50	1.9	od	1d	A
6772	2.5 0	2.25 1	2.52 1	2.53 1	*Ni*	2.33	5	3.6	2	2	A
6774	4.1 0	4.30 1	.....	.....	*La*	*4.28*	6	....	.....	.....	.....
6775	5.2 0	5.89 1	.....	.....	.....	.....	.....	.....	.....	.....	.....
6777	7.4 0	7.66 2	.....	.....	⊙	7.78	....	....	— 3N	.....	.....
6780	.....	.....	.....	0.48 1	.....	.....	.....	.....	.....	.....	.....
6781	1.81 10	1.93 1n	.....	.....	*TiO*	*1.93*	5	....	.....	.....	A
6783		3.59 3	3.80 2	.....	*Fe*	3.72	1	2.6	— 1	.....	C
	4.62 8				*V*	*5.02*	2	....	.....	.....	.....
6784		5.10 2	4.75 1	.....	*TiO*	*5.81*	4	....	.....	.....	C

TABLE III—*Continued*

Wave-Length Obs.	Betel-geuze	Alde-baran	Arc-turus	Pro-cyon	Identification				Sun		Con-trib-utor
					El.	W.-L.	Int.	E.P.	Dk.	Sp.	
6786		6.94 2	6.55 2		*Fe*	6.87	2	4.2	1	o	B
6789	9.7 o	9.96 1n	9.62 1		*Sa*+	9.97			− 2		
6791	1.5 o		1.15 1		*Zr*	*0.89*	10				
6793	4.05 3	3.70 3	3.49 2		*V*	3.64		0.1	0N	1	B
6796	6.36 2	6.29 3	6.18 1		*Fe*	6.14			o	1d	A
6798	8.55 2	8.65 3	8.82 1		*Ni*?	8.48	1	4.5	− 1	2	B
6801	1.18 2	1.26 1			⊙	1.21			− 3N		
6804	3.83 2	3.95 2	4.30 1		*Fe*	4.02		4.6	o	1	A
					Fe	4.31			o	− 2	C
6806	7.07 3	7.02 3	6.85 2		*Fe*	6.87	2	2.7	1	1d	A
6810	0.09 2	0.24 2	9.96 2		*Fe*	0.28	4	4.6	3	2	A
6812	2.55 2	2.58 2	o		*Zr*	*1.32*	2				
					V?	2.37		1.0	− 2N		C
					Zr	*2.66*	3				
6814			4.96 2		*Co*	4.97	40	1.9	o	1d	A
6815	5.42 4	5.18 3			*TiO*	*5.27*	5				A
					Fe−	9.61	pr	4.1	− 1d?	2	
6820	0.51 1	0.32 2	0.41 2		*TiO*	*0.17*	3				
					Fe	0.39			2	o	B
6821				1.27 1+							
6824	4.61 1				⊙	4.87			− 2N		
6825				5.14 1							
6825	5 85 1										
6827	7.62 1				*Mn*	*7.21*			− 2		
					⊙	7.97			− 2		
6828	8.67 1	8.35 3n	8.45 1	8.37 2	*Fe*	8.61	4	4.6	2	2	A
					Zr	*8.82*	10	1.4			C
6830	0.52 2	0.37 2n									
					V	*2.47*	2				C
6832	2.85 3	2.87 4		2.7 o	*Y*+?	2.49		1.6	− 3		C
					Zr	*2.03*	12	0.1			B
					Fe	3.26	1	4.6	− 1	− 2	
6833	3.64 1	3.9 o	3.3 o		*Mn*	*3.92*	4				
					Zr	*3.69*	4	1.4			
6835		5.3 o									
6837	7.14 2	7.06 1			*Fe*	7.03			o	− 1	C
					⊙	8.74			− 1	1d	
6839	9.29 2	9.76 1	9.59 1		*Fe*	8.85			o	o	
					V	*9.59*	2				
					Fe	9.85	2	2.5	1	2d	
					Fe	1.36	4	4.6	3	3	A
6841	1.93 2	1.65 2	1.55 2		*Ti*?	1.65		2.7	− 3N		
					V	*1.90*	2				C
6843			3.38 2		*Ni*	2.05	8	3.6	o	− 1	C
6843				3.89 1	*Fe*	2.70	2	4.6	1	1d	
6844	4.29 1	4.4 on			*Fe*	3.67	4	4.6	3	2	A
					Zr	4.70	pr	1.6	− 3		
6846	6.69 2	6.83 2	6.81 1		*Zr*	*5.30*	5				
					Zr	*6.42*	5	0.6			C
6847				7.16 1	*Zr*	*7.03*	18	1.5			A
6848			8.95 1		⊙	8.57			oNd	1	
					Zr	9.31	8	1.5	− 2N		
6850	0.21 3n	9.95 2n			*TiO*	*0.23*	5				A
					Ni	0.45	2		− 1N		
6851			1.97 1		*Fe*	1.66	pr	1.6	− 2		
6852	2.16 3n	2.15 2			*TiO*	*2.33*	6				A
6855	5.16 3n	5.09 3n	5.16 3	5.18 2	*Fe*	5.18	5	4.5	3	2	A
					Fe	7.27			o	1	B
6857	7.97 1n	8.14 1	7.87 1	7.62 2	*TiO*	*8.06*	4				
					Fe	8.17	3	4.6	2	2	A
6859				9.22 1							
6860	0.35 1	0.63 1	0.30 1		*Fe*?	0.34	1	2.6	− 2		
					Fe?	0.97	pr	2.8	− 2		
					Ti	1.52	6	2.3	− 2	2	
6861	1.99 3	1.88 3	1.81 4N		*Fe*	1.96	2	2.4	o	1d	
					Fe	2.51	2	4.5	1	o	
6881				1.46 1+	⊙	1.47			− 1		

TABLE III—*Continued*

Wave-Length Obs.	Betel-geuze	Alde-baran	Arc-turus	Pro-cyon	Identification				Sun		Con-trib-utor
					El.	W.-L.	Int.	E.P.	Dk.	Sp.	
6881	.....	.....	1.72 1	.....	*Cr*	1.73	2	3.4	0	3d	†
					Fe	1.73	1	4.5	1	1d	.....
					Cr	2.53	5	3.4	1	0d	.....
					Cr	3.07	10	3.4			
6910	0.30 1	.....	.....	.....	⊙	0 02	...	...	— 3N	.....	.....
6910	.....	.....	.....	0.81 1	⊙	0.71	...	...	— 3	.....	.....
6911	.....	.....	1.45 1	.....	*Fe*	1.54	1	2.4	— 1N	0d	.....
6914	4.57 2	4.54 2	.... ×	.....	*Ni*	4.58	50	1.9	4	3	A‡
6916	.....	.....	6.78 1	.....	*Fe*	6.69	3	4.1	2	1	.....
6921	.....	1.43 2N	.....	.....	.....	.....	...	...	.....	.....	§
6924	.....	4.42 2	.....	.....	*Cr*	4.10	10	3.4	0	.....	A‖
					Cr	5.29	6	3.4	1	2d	C
6926	6.07 1	5.99 2	6.27 2	6.08 1	*—Ti*	6.11	2	3.6	0	1d	.....
6928	8.07 1	×	.....	.....	.....	.....	...	...	.....	.....	¶
6930	0.68 1	0.69 1	.....	.....	.....	.....	...	...	.....	.....	.....
6931	.....	.....	1.21 1	1.30 1	*Mn*	1.13	5	...	.....	.....	.....
					Fe	3.05	pr	4.2	0N	— 1	.....
6933	3.38 4	3.30 3	3.49 4	3.28 3	*Mn*	3.58	4	...	.....	.....	.....
					FeAt	3.03	2	2.4	2	3	A
6935	.....	.....	.....	5.06 1	⊙	4.90	...	...	— 3	.....	.....
6945	5.58 4	5.42 4	5.16 2	5.26 2	*Fe*	5.22	4	2.4	4	4d	A**
6951	.....	.....	1.02 3	0.98 2	*Fe*	1.26	3	4.5	1	0d	.....
6951	1.78 3	1.32 3	.....	.....	*Fe*	1.65	pr	4.3	— 2	.....	††
					TiO	1.5	...	...	.....	.....	.....
6953	.....	.....	3.40 3	.....	*Zr*	3.87	20	0.6	.....	.....	A
6954	4.30 5n	4.48 5	.....	.....	*At*	3.59	...	...	.....	.....	‡‡
6957	7.87 2	.....	.....	.....	.....	.....	...	...	.....	.....	.....
6959	9.69 2	9.67 2	.....	.....	.....	.....	...	...	.....	.....	.....
6962	2.81 2n	2.80 2n	.....	.....	.....	.....	...	...	.....	.....	§§
6964	.....	.....	.....	4.12 2	.....	.....	...	...	.....	.....	.....
6965	5.2 0	6.04 3n	5.16 2	.....	*Ni*	.....	...	...	.....	.....	.....
6966	6.59 3	.....	.....	.....	*Zr*	6.49	12	1.6	.....	.....	A
6967	.....	.....	.....	7.83 1	*Mn*	8.00	3	...	.....	.....	.....
6969	.....	.....	.....	9 94 2	.....	.....	...	...	.....	.....	.....
6971	1.10 5N	1.28 3N	1.30 2N	.....	*Fe*	1.95	1	3.0	— 1	1	C
6973	.....	.....	.....	3.07 1	.....	.....	...	...	.....	.....	.....
6974			4.5 0		.....	.....	...	...	.....	.....	.....
6976	4.90 2n	5.07 3n	0.88 1	6.41 2N	*Fe*	6.28	1	4.6	— 2N	.....	.....
					Si	6.53	4	....	1	— 2	A
					At	7.18	...	...	.....	.....	.....
					Cr?	8.12	15	3.4	1N	2d	B
6978	8.77 7	8.79 6	8.77 4	8.94 2	*Fe*	8.88	3	2.5	2	3	A
					Cr	9.81	7	3.4	1	1d	C
6981	1.58 1	1 5 0	1.69 2	.....	.....	.....	...	...	.....	.....	.....
6982	.....	.....	.....	2.68 1	.....	.....	...	...	.....	.....	.....
6984	4.33 1	4.5 0	4.5 0	.....	.....	.....	...	...	.....	.....	.....
6986	6.58 1	6.76 1	6.26 2	6.06 2	*At*	6.59	...	...	.....	.....	.....
6988	8.76 4	8.46 1	.....	.....	*TiO*	8.51	1	...	.....	.....	C
					Fe	8.54	2	2.4	0	2	A
6990	0.49 4	0.44 1n	.....	.....	*Zr*	0.86	18	0.6	1	.....	A
6994	4.56 3	4.63 2	.....	.....	*Zr*	4.39	12	0.7	— 3	.....	A
6996	6.91 2	.....	.....	.....	*Ti*	6.68	1	2.3	.....	.....	B ‖ ‖
6999	9.75 4	9.80 2n	.....	.....	*Fe*	9.91	3	4.1	1	1	C
7001	1.63 2	1.50 1	1.69 1	.....	*Ni*	1.56	1	1.9	— 1	.....	C

† This line is too near the tail of the atmospheric B band for study.

‡ Blended with Atm 6913.6 in Arcturus.

§ Blended with Atm 6923.75.

‖ Separated from the atmospheric line at this wave-length by the large positive radial-velocity shift in Aldebaran.

¶ Blended with Atm 6929 in Aldebaran.

** Blended with Atm 6947.55 in Aldebaran and Betelgeuze.

†† On plates of Aldebaran and Betelgeuze this line is blended with Atm 6953.8. In Arcturus and Procyon the blend is with Atm 6950.7. Bobrovnikoff lists a *TiO* band at 6951.9 in α_1 Herculis.

‡‡ Blended with Atm 6956.4 in Betelgeuze and Aldebaran.

§§ On one plate of Betelgeuze two lines are barely resolved.

‖ ‖ Blend Atm 6998.98.

TABLE III—*Continued*

Wave-Length Obs.	Betel-geuze	Alde-baran	Arc-turus	Pro-cyon	Identification El.	W.-L.	Int.	E.P.	Sun Dk.	Sun Sp.	Con-trib-utor
7004	4.31 3	4.18 2									
7008	8.13 2	8.19 2	8.20 1		*Fe*	7.99	2	4.2	o	1d	
					Ti	8.32	1				B
7011	1.06 3	1.15 2	1.05 3		*Ti*	0.94	1				B
					At, Fe	1.34			2		
7012			2.87 1								
7014			4.88 1								
7016	6.21 3	6.39 4			*Fe*	6.08		4.6	1		
					Fe	6.45		4.1	3		
					At	6.45					
					Co	6.59	35				
7019			9.10 1								
7020	0.36 1		0.04 1N								
7022	2.90 2	2.8 0	3.01 2	3.00 2	*Fe*	2.97	3	4.2	2	2	A
					Fe	4.65	2	4.5	1	0d	
7024	4.59 2	4.80 2	4.43 2		*Ni*	4.89	3	4.5	o		
7027	7.22 1	7.37 1			*Zr*	7.40	15	0.6			A¶¶
7029		9.03 1	9.35 1		⊙	9.00			o		
					⊙	9.13			— 1		
7030		0.77 1									
7032		2.3 0	2.53 1		⊙	2.33			1	1	
7033	3.12 2N	3.4 0			*Ni*	4.41	1	3.5	— 3N		
7034		4.9 1	4.91 1		*Fe*	4.92		2.8	2N	1	
					Si	4.92	7	5.8			
7034				4.55 1+							
7037	8.46 6	8.51 6n	7.08 2		*At, Ni*	7.21	2	5.5	o		
					Fe	8.24	3	4.2	1	1d	
					Fe	8.79	1	4.2	o		
7039			9.02 4	9.20 2	*Ti*	8.83	3				B
7041			1.75 1								
7042	2.34 1				⊙	2.48			— 3		
7044	5.05 4n	4.98 2n	4.69 1		*Fe?*	4.69		4.9	— 1	— 1	C
7047	6.97 1n	7.3 0	7.09 1								
7048	×	8.91 1			⊙	9.01			— 3		
7049				9.91 1							
7050	0.36 2	0.71 1	0.68 2		*Ti*	0.68	1				B
7051				1.90 1							
7052	2.72 2	2.80 3	2.81 3		*At*	2.79			1	o	
					Co?	2.93	60	1.9	o	—	
7054	4.29 10	4.76 5n			*TiO*	4.51	8				A
7056			6.41 1	6.36 1	⊙	6.48			— 3		
7058			8.79 1								
					Ba	9.94	400	1.2	—	—	
7060	9.92 4	0.12 2	0.31 2		*TiO*	0.01	3				
					At−	0.45			1N	o	
7063	2.85 1	3.14 1	3.00 1		*Ni*	2.99	4	1.9	— 2N		A
7066	6.11 1	6.15 2n	5.95 2		*La+*	6.23	300	0.0	— 2d		C
7068	8.73 2n	8.75 3	8.77 2		*Fe*	8.42	3	4.9	2	1	B
					Ti	9.09	2	3.2	— 3N	— 1	B
7072	2.0 0										
	2.9 0	2.5 0	2.21 1n		*Fe*	1.87	1	4.6	oN	— 3	B
7074	4.89 1	4.4 0	4.81 1n								
7076	6.86 1	6.49 1	8.45 2N								
7079	9.24 1	9.28 1									
7082	3.13 1	2.67 1									
7084	4.77 3	4.72 5	4.86 4		*Co*	4.99	100	1.9	2N	3	A
					TiO	7.89	12				A
7087	7.15 10	7.88 5			*Zr*	7.35	20	0.6			C
7088			8.07 1	7.89 1							
7090	0.05 4	0.30 1	0.46 2		*Fe*	0.40	3	4.2	2	2	B
7090				0.71 1							
7092	2.97 5n	3.07 1	2.92 1		*TiO*	3.17	4				A***
					Zr	4.61	7	1.5			A
7095	5.18 3	5.40 1n	5.37 1		*Fe*	5.42	2	4.2	o	— 1	B
					Zr	5.66	8	1.5			A
7097	7.60 2	7.74 1	7.76 1		*Zr*	7.78	25	0.7			A
7099	9.41 2	9.4 0	9.9 0								

¶¶ Separated from Atm 7027.49 by radial velocity shift.

*** Not due to *TiO* in Arcturus.

TABLE III—*Continued*

Wave-Length Obs.	Betel-geuze	Alde-baran	Arc-turus	Pro-cyon	Identification				Sun		Con-trib-utor
					El.	W.-L.	Int.	E.P.	Dk.	Sp.	
7100...	0.99 2	1.3 .0	.....	.....	.....	.....	.....	.....	.....	.....	.....
7103...	3.10 3n	3.32 4n	2.85 2n	.....	*Zr*	2.95	20	0.6	.....	.....	A
					Zr	3.77	18	0.0	.....	.....	A
7105...	.....	.....	.....	5.66 1	.....	.....	.....	.....	.....	.....	.....
7107...	7.66 2	7.28 2n	7.35 1	.....	*Fe*	7.48	1	4.6	0	1	A
					Ni	0.92	3	1.9	1	1d	B
7111...	1.47 4n	1.44 4n	1.14 2n	.....	*Zr*	1.71	12	0.5	.....	.....	A
					Fe	2.19	1	3.0	0	1	B
7115...	5.09 2n	5 05 1	4.96 1n	.....	.....	.....	.....	.....	.....	.....	.....
7117...	7.22 1	7.49 1	7.66 1N	.....	.....	.....	.....	.....	.....	.....	.....
7119...	9.82 1	0.13 1	9.72 1N	.....	.....	.....	.....	.....	.....	.....	.....
7122...	2.63 1	2.39 2	2.34 2	1.99 2	*Ni*	2.22	100	3.5	4	6	A
7125...	5.14 9	6.01 5n	.....	.....	*TiO*	5.61	14	....	.....	.....	.....
7127...	.....	.....	7.42 1	.....	.....	.....	.....	.....	.....	.....	.....
7130...	.....	0.91 3n	0.71 2n	0.86 1	*Fe*	0.94	4	4.2	3	4	.....
7131...	1 6 4N	.....	.....	.....	*TiO*	1.34	5	....	.....	.....	.....
7133...	.....	3.39 2	3.51 1n	.....	.....	.....	.....	.....	.....	.....	.....
7135...	5.66 1	5.69 2	5.96 1	.....	*Ti*	5.54	1	....	.....	.....	B
7139...	9.61 1	9.20 4n	9.20 2N	.....	*At, Ti*	8.95	1	1.4	— 2	2	B
7142...	.....	2.35 1	2.68 1	2.36 1	*Fe*	2.53	....	....	0	— 2	A
7143...	.....	3.7 0	.....	.....	.....	.....	.....	.....	.....	.....	.....
7145...	.....	5.39 1	5.29 1	.....	*Fe*	5.32	1	4.6	1	— 1	A
7148...	8.4 0	8.35 3	8.06 4	8.10 2	*Ca*	8.16	10	2.7	3N	7	A
7151...	1.39 1	1.25 2	1.02 2	.....	*Mn*	1.28	3	....	.....	.....	.....
					Fe	1.48	1	2.5	— 1	.....	.....
7153...	.....	3.1 0	.....	.....	.....	.....	.....	.....	.....	.....	.....
7155...	5.4 2	5.33 3	5.45 2	.....	*Fe*	5.65	1	5.0	0N	0	.....
7155...	.....	.....	.....	5.97 1N	.....	.....	.....	.....	.....	.....	.....
7158 } 7160	9.72 4N	8.87 2	8.69 1	8.47 1N	*TiO*	9.03	6	....	.....	.....	B
		0.38 2	0.56 1	.....							
7161...	.....	.....	.....	1.67 1N	.....	.....	.....	.....	.....	.....	.....
7163...	.....	.....	.....	3.92 1	.....	.....	.....	.....	.....	.....	.....
7164...	5.17 1	4.44 2	4.48 4	.....	*TiO*	4.31	4	....	.....	.....	†††
					Fe	4.45	4	4.2	2	4	A
7165...	.....	.....	.....	5.48 1	*Si*	5.57	15	5.8	1N	— 2	A
7169...	.....	9.02 3	.....	.....	*Zr*	9.14	40	0.6	.....	.....	A‡‡‡
7174...	4.61 2	.....	.....	.....	*Mn*	4.46	.....	.....	.....	.....	.....
7177...	7.93 1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7180...	0.00 2	.....	.....	.....	*Fe*	0.01	....	1.5	— 2	.....	.....
7181...	1.17 2	.....	.....	.....	*Fe*	1.21	2	4.2	0	1	.....
7187...	6.96 1	7.30 1	.....	.....	*Fe*	7.39	5	4.1	5N	.....	A§§§
7188...	8.78 2N	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7190...	0.16 2	.....	.....	.....	*Ti*	9.92	2	2.6	.....	.....	B
7197...	7.47 4	7.16 2	.....	.....	*Ni*	7.02	5	1.9	0	1	A|||₁
					TiO	7.67	3	....	.....	.....	A
7203...	3.74 1	.....	.....	.....	*TiO*	3.64	4	....	.....	.....	A
7207...	7.69 2	7.49 4	7.46 1	.....	*Fe*	7.41	3	4.1	1	0	C¶¶¶
7209...	9.53 4	9.59 4	9.43 4	.....	*Ti*	9.51	5	1.5	3	6	A****
					At	9.51	....	....	.....	.....	.....
7211...	.....	.....	.....	1.05 1	.....	.....	.....	.....	.....	.....	.....
7213...	3.66 3N	3.65 4N	.....	.....	.....	.....	.....	.....	.....	.....	.....
7214...	.....	.....	.....	4.96 1	.....	.....	.....	.....	.....	.....	.....
7216...	6.48 3	6.40 2	6.37 3n	.....	*Ti*	6.19	5	1.4	— 2	3	A††††
					At	6.54	....	....	2	.....	.....
7217...	.....	.....	.....	7.86 1	.....	.....	.....	.....	.....	.....	.....
7219...	9.37 1	9.49 1	.....	.....	*TiO*	9.40	6	....	.....	.....	B
7221...	1.47 1	1.41 3	.....	.....	*Fe*	1.22	1	4.5	0	— 2	C

††† Blended with Atm 7167 in Aldebaran.

‡‡‡ Blend with Atm 7170.3.

§§§ Listed as due to *Fe*-Atm in *Revised Rowland*. The stellar component is clearly separated in Aldebaran by velocity shift.

||| ||| The *Ni* line 7197.02 is separated from Atm 7197.23 by radial velocity shift in Aldebaran. May be blended with Atm 7198.4.

¶¶¶ Blended with Atm 7206.43 in Arcturus. Blended with Atm 7209.51 in Aldebaran and Betelgeuze.

**** Blended with Atm line at same wave-length in Arcturus. The stellar component is clearly separated in Aldebaran.

†††† Blended with Atm 7216.54 in Arcturus. Separated in Aldebaran and Betelgeuze.

TABLE III—*Continued*

Wave-Length Obs.	Betel-geuze	Alde-baran	Arc-turus	Pro-cyon	Identification				Sun		Con-tribu-tor
					El.	W.-L.	Int.	E.P.	Dk.	Sp.	
7223...	3.76 3	3.73 2	3.41 5	.....	*Fe*	3.65	2	3.0	3	.....	.....
					At	3.65	.....	.....	3	.....	‡‡‡‡
7228...	9.02 3	8.76 3	8.41 2	.....	.....	.....	.....	.....	.....	.....	.....
7236...	6.80 3n	6.39 1	.....	.....	.....	.....	.....	.....	.....	.....	.....
7240...	0.25 3n	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7244...	4.85 5	4.86 3	.....	.....	*Ti*	4.87	4	1.4	— 1	4	A
					Fe	4.87	2	4.9			
7245...	.....	.....	5.34 2	.....	.....	.....	.....	.....	.....	.....	.....
7246...	6.83 1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7248...	.....	.....	.....	8.5, 1	.....	.....	.....	.....	.....	.....	.....
7251...	1.68 5	1.63 3	.....	.....	*Ti*	1.73	4	1.4	— 2N	3	A§§§§
7254...	3.98 1	4.07 1n	.....	.....	*Ti*	3.76	1	.....	.....	.....	.....
7258...	9.01 1	8.81 1	.....	.....	.....	.....	.....	.....	.....	.....	.....
7259...	.....	.....	.....	9.95 1n	.....	.....	.....	.....	.....	.....	.....
7261...	1.27 5	1.59 5	1.52 4	1.69 1n	*Fe*	1.52	.....	.....	— 1N	.....	|||||
					Ni	1.93	.....	.....	.....	.....	.....
					At–	2.01	.....	.....	1	.....	.....
7264...	.....	.....	4.70 2	.....	.....	.....	.....	.....	.....	.....	.....
7266...	6.27 2	6.25 1	.....	.....	*Ni*	6.15	.....	.....	— 3N	.....	.....
					TiO	9.05	6	.....	.....	.....	A
7271...	1.31 5	×	.....	.....	*At*	2.99	.....	.....	5N	.....	.....
					TiO	3.93	5	.....	.....	.....	A
7278...	8.12 2N	8.56 1n	.....	.....	.....	.....	.....	.....	.....	.....	.....
7280...	.....	.....	.....	0.40 2	.....	.....	.....	.....	.....	.....	.....
7280...	0.95 1n	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7281...	1.62 5n	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7282...	.....	2.24 2n	2.18 1n	.....	.....	.....	.....	.....	.....	.....	.....
7284...	4.32 3	.....	.....	.....	*Mn*	3.81	6	4.4	— 3N	.....	.....
					Fe	4.85	.....	.....	— 1	— 1	.....
7285...	.....	5.34 3n	.....	.....	*Fe*	5.28	.....	2.9	— 2	— 3	.....
7288...	8.62 4	.....	.....	.....	*Fe*	8.76	3	4.2	— 1	— 1	.....
					Si	9.20	500	5.6	oNd?	— 3	.....
7291...	1.11 5	1.25 3	.....	.....	*TiO*	0.80	5	.....	.....	.....	A
					Ni	1.46	1	1.9	— 1	0	A
7292...	.....	.....	.....	2.33 1	.....	.....	.....	.....	.....	.....	.....
7293...	3.04 2	3.15 3	2.87 2	.....	*Fe*	3.06	1	4.2	— 2N	.....	.....
7295...	5.05 2	5.31 1	.....	.....	*Fe*	5.05	.....	.....	1	.....	A
7297...	7.50 3	7.88 2	.....	.....	*TiO*	7.01	3	.....	.....	.....	A
7299...	9.43 4	9.64 2	.....	.....	*Ti*	9.65	2	1.4	oN	.....	A¶¶¶¶
7302...	2.79 4	2.7 3n	.....	.....	*Mn*	2.87	6	4.4	— 3	.....	C*****
7307...	7.90 4	8.06 3n	.....	.....	*Ti*	8.18	1	.....	.....	.....	A
					Fe+	0.21	pr	3.9	— 1	.....	C
7310...	0.65 3	.....	0.67 2	0.50 1	*Fe*	1.10	2	4.3	oNd?	— 1	C
7311...	.....	1.19 3	.....	.....	*Fe*	1.10	2	4.3	oNd?	— 1	.....
7312...	2.54 1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7315...	5.36 4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7318...	.....	8.32 3	.....	.....	*Ti*	8.43	2	.....	.....	.....	A
7319...	9.98 2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7320...	.....	0.88 1	0.69 1	0.48 2	*Fe*	0.69	0	3.9	1	1	B
					Fe+	0.69	.....	4.9			
7322...	2.91 5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7323...	.....	3.87 2	.....	.....	.....	.....	.....	.....	.....	.....	.....
7325...	5.47 4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7326...	.....	6.12 4	6.42 3	6.53 4	*Ca*	6.18	2	2.9	0	5	B
					Mn	6.50	7	4.4	— 2	.....	B
7337...	.....	7.67 1	7.47 1	.....	.....	.....	.....	.....	.....	.....	.....
7338...	8.54 1	.....	.....	.....	*V*	8.93	3	.....	.....	.....	.....
7339...	.....	9.18 1	.....	.....	.....	.....	.....	.....	.....	.....	.....
7344...	4.30 8	4.54 5	4.30 5	.....	*Ti*	4.74	3	1.5	— 2	.....	A†††††
7346...	6.64 1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7350...	.....	.....	0.29 2N	.....	.....	.....	.....	.....	.....	.....	.....
7351...	0.89 3	1.17 3n	.....	.....	*Ni*	1.16	.....	.....	.....	.....	.....

‡‡‡‡ Separated from Atm line at same wave-length in Aldebaran and Arcturus.

§§§§ Separated from Atm 7252.9 by velocity shift in Aldebaran.

|| || || || Blend with Atm 7262.01.

¶¶¶¶ The titanium line is separated from the terrestrial component in Aldebaran.

***** Blended with Atm 7304.19 in Aldebaran.

††††† May be blended with Atm 7343.95 and 7344.76 in Arcturus.

TABLE III—*Continued*

Wave-Length Obs.	Betel-geuze	Alde-baran	Arc-turus	Pro-cyon	Identification				Sun		Con-trib-utor
					El.	W.-L.	Int.	E.P.	Dk.	Sp.	
7355	5.94 5	5.95 3	5.89 3	6.00 1	*Cr*	5.89	10	2.9	1	5	A
7357	7.81 5	7.76 2	7.60 2	.....	*Ti*	7.76	3	1.4	— 1	.....	A
7360	.....	.....	0.21 1	0 17 1	.....	.....	.....	.....	.....	.....	.....
7361	.....	.....	1.65 1	1.48 1	*Al*	1 58	6	.....	.....	.....	C
7362	2.16 3	2.01 4	.....	.....	*Al*	2.32	10	.....	.....	.....	C
					Fe	2.32	0	1.6	.....	.....	C
7363	.....	.....	.....	3 38 1	.....	.....	.....	.....	.....	.....	.....
7364	4.17 4	4.05 3	4.02 3	.....	*Ti*	4.04	2	1.4	— 2	.....	A
7365	.....	.....	.....	5.18 1	.....	.....	.....	.....	.....	.....	.....
7366	6.64 3	6.70 3	6.41 3	6.45 1	*Fe*	6.41	.....	.....	.....	.....	A
					Ti	6.58	1	1.4	.....	.....	B
7368	.....	.....	.....	8.31 1	.....	.....	.....	.....	.....	.....	.....
7369	9.80 3n	9.58 2n	.....	.....	*Fe*	0.18	.....	.....	— 1N	.....	.....
7370	.....	.....	.....	0.99 1	.....	.....	.....	.....	.....	.....	.....
7372	2.59 1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7373	.....	3.00 1n	3.31 1	3.11 1	⊙	3.06	.....	.....	— 1	.....	.....
7374	.....	.....	4.74 1	.....	.....	.....	.....	.....	.....	.....	.....
7375	.....	.....	.....	5 56 1n	.....	.....	.....	.....	.....	.....	.....
7376	6 71 2n	6.56 1n	6.42 1	.....	.....	.....	.....	.....	.....	.....	.....
7377	.....	.....	.....	7.32 1	.....	.....	.....	.....	.....	.....	.....
7382	2.20 4	2.30 3n	2.57 2n	2.55 2n	*Ni*	2.00	.....	.....	— 1	.....	.....
					Ni	5.30	1	.....	1	.....	.....
7385	5.65 4	5.74 2n	5.38 1N	.....	*Ni*	6.24	.....	.....	— 2	.....	.....
					Fe	6.37	.....	.....	1N	.....	.....
7386	.....	.....	.....	6.77 2N	⊙	7.74	.....	.....	1N	.....	.....
7389	9.88 5	9.48 4	9.31 2	9.53 2	*Fe*	9.39	3	4.3	2	1	B
7390	.....	.....	0.84 1	0.88 2	.....	.....	.....	.....	.....	.....	.....
7393	3.66 3	3.63 3	3.55 2	3.49 1	*Ni*	3.61	10	3.6	2	1	A
7396	.....	.....	6.30 2	6.24 1	.....	.....	.....	.....	.....	.....	.....
7397	.....	7.81 1n	.....	.....	.....	.....	.....	.....	.....	.....	.....
7400	0.39 5	0.23 3	0.17 2	0.34 2n	*Cr*	0.18	10	2.9	1	4	A
7401	.....	1.64 1	1.66 1	.....	*Ni*	1.12	4	5.6	.....	.....	.....
7403	.....	.....	.....	3.13 1	.....	.....	.....	.....	.....	.....	.....
7405	.....	.....	5.81 2	5.81 2	*Si*	5.79	200	.....	1	— 1	A
					Si	5.95	200	5.6			
7406	6.21 3	6.09 1	.....	.....	.....	.....	.....	.....	.....	.....	.....
7409	9.27 3	9.15 2	9.22 2	9.23 2	*Si*	9.11	100	5.6	0	.....	B
					Ni	9.35	8	5.5 3.8	1	0	B
7411	1.27 3	1.23 2	1.05 2	1.17 1	*Fe*	1.16	3	4.3	1	1	A
7414	4.71 4	4.69 3	4.65 2	4.36 1	*Ni*	4.51	2	2.0	1	1	A
7415	.....	.....	.....	5.88 3n	*Si*	5.96	250	5.6	1	— 2	A
7417	8.00 3d	7.38 2	7.73 1	7.5 0	*Co*	7.39	10	.....	.....	.....	B
7418		8.76 1	9.20 1	9.0 0	*Fe*	8.67	.....	.....	0	— 1	B
					Ni	2.29	15	3.6	1	0	A
7422	3.35 10n	3.30 6n	2.19 3	3.30 3n	*Si*	3.51	400	5.6	1	— 3	A
7423			3.87 3		*Si*	4.05	20	5.6	— 1	.....	A
					Ti	3.12	2	1.4	.....	.....	.....
7430	1.11 3	0.76 3n	1.01 2n	.....	*Fe?*	0.87	.....	.....	— 1	.....	.....
7432	2.94 3	2.82 3	.....	2.63 1	*V?*	1.61	.....	.....	— 2	.....	.....
7433	.....	.....	3.48 1	.....	*Ni*	3.48	.....	.....	— 2	.....	.....
7435	.....	5 66 1	.....	.....	⊙	5 61	.....	.....	— 1	.....	.....
7437	.....	7.21 1	.....	.....	.....	.....	.....	.....	.....	.....	.....
7440	0.35 5	0.37 4	0.66 2	.....	*Zr*	0.89	20	0.5	.....	.....	A
					Ti	0.58	3	.....	— 2	.....	A
					Fe?	0 92	.....	.....	1	0	.....
7442	2.99 2	2.96 1	3.02 1	.....	*Fe*	3.04	.....	.....	0	.....	.....
					Mn	3.49	.....	.....	.....	.....	.....
7445	5.71 3	5.78 3	5.70 2	5.75 1	*Fe*	5.76	3	2.3	2	3	A
7448	.....	.....	8.99 1	.....	.....	.....	.....	.....	.....	.....	.....
7450	.....	.....	0.29 1	.....	.....	.....	.....	.....	.....	.....	.....
7451	.....	.....	1.66 1	.....	.....	.....	.....	.....	.....	.....	.....
7456	6.80 3	6.59 2	6.63 1	.....	⊙	5.43	.....	.....	— 2	.....	.....
					Co	7.35	.....	.....	— 2	.....	.....
7458	.....	.....	8.69 1	.....	⊙	8.40	.....	.....	— 2?	.....	.....
7462	2.12 6	2.10 5	2.00 3	2.26 2	*Cr*	2.34	10	2.9	2	5	A
					Fe+	2.34	pr	3.9			
7469	9.91 1	0.67 2n	.....	.....	.....	.....	.....	.....	.....	.....	.....
7471	1.53 1										

TABLE III—*Continued*

Wave-Length Obs.	Betel-geuze	Alde-baran	Arc-turus	Pro-cyon	Identification				Sun		Con-tribu-tor
					El.	W.-L.	Int.	E.P.	Dk.	Sp.	
7475	5.55 2	4.99 1	5.58 1	.....	*Ti*	*4.93*	1	1.7	.....	.....	B
					⊙	*5.25*	....	....	— 2N	.....	.....
7479	9.42 1	.....	.....	.....	⊙	*9.73*	....	....	— 2	.....	.....
7481	1.90 1	1.95 2N	1.55 1	.....	*Ni*	*1.50*	2	....	— 2	.....	B
7482	.....	.....	.....	2.53 1s	.....	.....	....	....	.....	.....	.....
7483	3.66 3	4.06 2N	.....	.....	.....	.....	....	....	.....	.....	.....
7483	.....	.....	.....	3.89 1s	.....	.....	....	....	.....	.....	.....
7489	9.39 2	9.42 2	9.41 1	.....	*Ti*	*9.60*	2	....	— 2	.....	B
7491	.....	.....	.....	1.25 1	.....	.....	....	....	.....	.....	.....
7491	1.71 2	1.76 2	1.69 2	.....	*Fe*	1.65	2	4.3	1	1	A
7495	5.19 6	5.02 4	5.02 2	5.18 2	*Fe*	5.08	3	4.2	2.	3	A
7498	.....	8.53 1	.....	.....	*Fe*	*8.56*	....	....	— 1	.....	.....
7505			5.96 2	.....	⊙	*6.06*	....	....	— 1	.....	.....
7507	7.08 1	7.22 2n	7.97 2	.....	*Fe*	7.28	.. .	4.4	1	1	.....
7511	1.09 3	1.07 3	0.98 3	1.01 3	*Fe*	1.03	4	4.2	2	3	A
7522	.....	.....	2.73 2	2.85 1	*Ni*	2.78	3	3.6	1	0	A
7523	3.01 2	3.06 3	.....	.....	.....	.....	....	....	.....	.....	.....
7525	5.32 1	5.25 2	5.37 1	5.15 1	*Ni*	5.12	2	3.6	1	0	A
7528	.....	.....	8.72 1	.....	.....	.....	....	....	.....	.....	.....
7531	1.05 1	1.11 2	1.16 3	1.02 1	*Fe*	1.15	....	4.4	2	2	A
7536	.....	.....	6.73 1	.....	.....	.....	....	....	.....	.....	.....
7537	.....	.....	.....	7.95 1	.....	.....	....	....	.....	.....	.....
7540	0.20 1	0.19 2	0.33 2	.....	⊙	*0.46*	....	....	— 2	.....	.....
7543	.....	3.60 1	.....	.....	.....	.....	....	....	.....	.....	.....
7546	6.40 3	6.45 3	6.71 3	.....	*Fe*	*6.19*	....	....	1	.....	B
					⊙	*9.11*	....	....	— 2	.....	.....
7550	.....	0.51 1n	.....	.....	⊙	*1.13*	....	....	— 2	.....	.....
					Zr	*4.73*	10	0.6	.....	.....	.....
7554	.....	4.6 0	.....	.....	⊙	*4.86*	....	....	— 1	.....	.....
7555	5.16 3	5.31 2d	5.38 3	5.58 2	*Ni*	5.61	5	3.8	2	2	B
7558	.....	.....	8.34 1	.....	.....	.....	....	....	.....	.....	.....
7559	×	9.43 2	.....	.....	*NiFe*	*9.71*	....	....	0	.....	B
7560	.....	.....	0.60 1	.....	.....	.....	....	....	.....	.....	.....
7563	.....	3.32 1	2.94 1	.....	*Fe*	*3.02*	....	....	— 1	.....	A
7568	9.02 3	8.84 2	9.09 3	8.57 2	*Fe*	8.91	2	4.3	1	0	A
7574	4.47 3	4.43 3	4.19 3	4.20 2	*Ni*	4.05	1	3.8	1	0	A
7583	3.75 2	3.63 2	3.75 3	.....	*Fe*	3.80	2	3.0	1	2	A
7586	6.27 2	6.33 2	6.23 2	6.12 1	*Fe*	6.03	....	4.3	2	2	A
7589	9.79 3	9.09 1n	.....	.....	*TiO*	*9.62*	8	....	.....	.....	A

DISCUSSION OF STELLAR LINES BETWEEN 6562 A AND 7593 A

Hydrogen (*1*).—Hydrogen is represented by the line *Hα*, which has been taken as the starting-point for this investigation. The line is present on all spectrograms, with an intensity too strong for calibration.

Helium (*2*).—Since no B stars are included in this study, it is not to be expected that the helium lines would be evident. A number of plates of various B-type stars show quite strongly the line 6678 A. The lines 7065 A and 7281 A should also be present in B-type stars.

Lithium (*3*).—The ultimate doublet of lithium at 6707.83 A has an intensity of 4 in the sun-spot spectrum. It should be present in

Aldebaran and Betelgeuze. A line at 6707.43 A, intensity 2, in Aldebaran may be due to lithium, but the discrepancy in wave-length is rather high. It may be blended with a line of shorter wave-length,

TABLE IV

LINES IN VEGA AND SIRIUS, 6562–7593 A

Wave-Length Obs.	Vega Int.	Sirius Int.	Identification				Sun		Contributor
			El.	W.-L.	Int.	E.P.	Disk	Spot	
6562.8	20	20	*H*	2.82		10.155	40	20	A
6586.8	0	1n							*
6588.3	1n								
6591.4	1n		*Fe*	1.35			— 1	— 2	
6594.1	1n								
6717.5	1		*Fe*?	7.54		4.587	— 2		
6719.7	1								
6772.8	1								
6794.6	2	0	⊙	4.63			— 2		
6932.4	2		⊙	2.51			— 3		
6973.9	1								
7001.7	1	1							
7042.0	1								
7043.1	1								
7044.6	1		*Fe*	4.69		4.934	— 1	— 1	
7078.7	2								
7080.6	1								
7161.3	1								
7162.9	2								
7167.3	1								
7212.5	2		*Fe*	2.44		4.934	— 1		
7306.5	1		*Fe*	6.58		4.168	— 1	— 2	
7321.2		1							
7341.7	1								
7354.8	1								
7356.7		1							
7360.7		1							
7363.8	1		*Fe*	3.97		4.934	— 2		
7372.3	1								
7379.0	1								
7389.5	1		*Fe*	9.39	3	4.283	2	1	B
7406.3		1							
7408.1		1							

* A line is present at this wave-length on plates of Rigel, γ Orionis, and γ Pegasi.

but even the partial identification of the measured line in Aldebaran with the lithium line must be considered doubtful.

Carbon (6).—No strong neutral carbon lines occur in this region. *C* II 6578 A and 6582 A appear on plates of Rigel, γ Orionis, and other B-type stars.

Nitrogen (*7*).—The line 7468.7 A is not observed on spectrograms of Vega or Sirius, possibly because the spectra are of slightly inferior quality at this point. Merrill[5] reports this line as present in α Cygni, intensity 2. He also records *N* I 7423.88 A, intensity 0, and 7442.56 A, intensity 0.

Oxygen (*8*).—A line at 7001.7 A in Vega and Sirius may be *O* I 7002.2, although the discrepancy in wave-length is rather large.

Fluorine (*9*).—Most of the strong lines of neutral fluorine listed by Miss Moore in her compilation, "A Multiplet Table of Astrophysical Interest," are in the spectral region under consideration. They do not occur on any of the plates studied. They should be looked for in early-type stars because of their high excitation potentials, 12–13 volts.

Neon (*10*).—Recently some of the strong neon lines in the red were reported[6] by Miss MacCormack to be present in Rigel and γ Pegasi. When spectrograms of these stars in the extreme red become available, they should be examined for the strong neon lines of this region.

Magnesium (*12*).—Neither *Mg* I 7193 A nor 7387 A occurs on any of the plates examined.

Aluminum (*13*).—Two lines of neutral aluminum at 6696.04 A and 6698.68 A appear on plates of Arcturus and Aldebaran.

Silicon (*14*).—Practically all of the neutral silicon lines listed by Miss Moore are slightly weakened in the sun-spot spectrum. Consequently it is anticipated that the lines will be relatively weak in Betelgeuze and Aldebaran as compared with Arcturus and Procyon. Table V illustrates this.

Sulphur (*16*).—The case for neutral sulphur in the sun has recently been presented by Miss Moore and Babcock.[7] In their discussion they state:

> The presence of the group at λ 6743 is more doubtful, if the spot intensities in this region are considered. Two of the lines, λ 6743 and λ 6757, have each been assigned a spot intensity of −2N which precludes their identification as *S*, of excitation potential 7.8 volts, since lines of this excitation would be completely obliterated. The absence of this multiplet makes the presence of the later series members extremely doubtful.

[5] *Ap. J.*, **79**, 183, 1934.

[6] *Pub. A.S.P.*, **46**, 64, 1934.

[7] *Ap. J.*, **79**, 492, 1934.

On the basis of the present work,[8] this group may now be unqualifiedly identified as due chiefly to sulphur since the lines are present in Procyon and absent from all the other stars considered. The fact that two lines of the group, 6757 A and 6743 A, are not obliterated in the spot spectrum indicates a blend with some other element, as pointed out by Miss Moore and Babcock.

Attention is further called to the fact that Dunham in his work on α Persei[9] records three lines which agree so well in wave-length with the sulphur group at 4696 A as to leave little doubt as to their source.

TABLE V

LINES OF *Si* I

WAVE-LENGTH*	INT.	E.P.	SUN		BETEL-GEUZE	ALDE-BARAN	ARC-TURUS	PRO-CYON	NOTES, BLENDS
			Disk	Spot					
6976.80....	10	.....	1	−2	.....	.....	1	2N	Atm 7.48 *Fe* 6.28
7034.92....	50	5.846	2N	1	.....	1	1	1+	*Fe* 4.92
7405.94....	300	5.589	1	−1	.....	.....	2	2	
7409.14....	100	5.591	0	.....	3	2	2	2	*Ni* 9.35
7416.08....	250	5.591	1	−2	.....	.....	.....	3n	
7423.64....	500	5.595	1	−3	10n	6n	3	3n	*Ni* 2.28
7424.70....	20	5.594	−1	.....					

* Laboratory data from Kiess, *Bur. of Stand. J. of Research*, 11, 775, 1933.

A well-exposed three-prism plate of Procyon taken at the Yerkes Observatory was examined for the group at 4696 A. The lines are unquestionably present. They do not appear in Albrecht's[10] table of lines in Procyon, doubtless because his plates are rather weak in this region. The data for sulphur are assembled in Table VI.

The presence of *S* II lines in the sun was recently suggested by Bartelt and Eckstein.[11] In the paper by Miss Moore and Babcock they show quite conclusively that the coincidences are due to chance. As they point out, the high ionization potential of *S* is wholly inconsistent with the presence of *S* II lines in the sun. Sometime ago the

[8] Announced in *Science*, **80**, 73, 1934.

[9] *Pub. of the Princeton Obs.*, No. 9, 1929.

[10] *Ap. J.*, **80**, 86, 1934.

[11] *Zs. f. Ap.*, **7**, 272, 1933.

writer[12] found that these lines come to a maximum of intensity at about B5. They persist in some of the early A-type stars, but are not strong even at their maximum and hence cannot be expected as late as Go. The one ionized sulphur line in the region studied in this paper is a weak one at 6981.65 A. It is not observed in Vega.

TABLE VI

LINES OF *S* I

LABORATORY			SUN		α PERSEI (DUNHAM)	PROCYON
Wave-Length	Int.	E.P.	Disk	Spot		
4694.13	10	6.50	oN	ob?	4.11 2	4.03 1+
4695.45	8	6.50	oN	oBd	5.44 1	5.32 1−
4696.25	6	6.50	−1N	.....	6.25 1	6.47 o
6743.58	6	7.83	−2N	−2N?	.....	3.52 1−
6748.79	8	7.83	−2	.....	.....	8.69 1
6757.16	10	7.84	−1d?	−2N	.....	7.25 1+

TABLE VII

LINES OF *Ca* I

Wave-Length (Sun)	Int.	E.P.	Disk	Spot	Betelgeuze	Aldebaran	Arcturus	Procyon	Vega
6572.804	8	0.000	1	6	3	3	2	.....	.....
6717.697	30	2.697	5	8	4	3	4	2	1
7148.163	10	2.697	3N	7	o	3	4	2	.....
7202.211	3	2.697	1N	5	.....	.....	.....	.....	*
7326.176	2	2.920	o	5	4	4	3	4	†

* Masked by Atm lines.

† Blended with Atm 7327.38 A and *M*n 7326.53 A (Procyon). The line in Betelgeuze is shifted about half an angstrom toward the violet, indicating another contributor.

Chlorine (*17*).—Two lines of chlorine of excitation potential 8.9 are found in the laboratory at 7256.65 A and 7547.09 A. No evidence for their presence in either Procyon or Vega has been found.

Argon (*18*).—The argon lines in the extreme red have too high an excitation potential to occur in stars of spectral classes later than A. Evidence of the presence of argon lines is lacking on the plates of Vega considered here. The presence of ionized argon in *υ* Sagittarii (B8p) was recently demonstrated by W. W. Morgan.[13]

[12] *Ap. J.*, **72**, 191, 1930. [13] *Ibid.*, **79**, 513, 1934.

Calcium (*20*).—Five strong calcium lines are observed in the laboratory in the extreme red. Their occurrence on the plates measured is indicated in Table VII.

TABLE VIII

Ti I LINES, 6562–7593 A

WAVE-LENGTH	INT.	E.P.	SUN		BET.	ALD.	ARC.	PROC.	NOTES, BLENDS
			Dk.	Sp.					
6599.13	3	0.896	−1	4	4	3	3	1	*Ni* 8.62
6666.60	2n	1.454	−2N	od	2N	3N	1N	.....	Blend at longer wave-length
6743.15	2	0.896	1	4	2	2	3	.....	
6861.47	2	2.258	−2	2	3	3	4N	.....	*Fe* 1.95; *Fe* 2.51
6926.11	2	3.567	0	1d	1	2	2	1	
6996.69	1	2.324	−3	−1	2	.....	.....	.....	
7008.32	1	.....	.....	.....	2	2	1	.....	*Fe* 7.99
7010.94	1	.....	.....	.....	3	2	3	.....	*Fe;* Atm 1.34
7038.83	3	.....	.....	.....	6	6	.....	.....	*Fe* 8.24
7050.68	1	.....	.....	.....	2	1	2	.....	
7069.11	2	3.166	−3N	−1	2n	3	2	.....	*Fe* 8.42
7138.92	1	1.437	−2	2	1	4n	2N	.....	Atm and *Ti* lines separated in Bet. and Ald.
7189.92	2	2.567	−2	.....	2	.....	.....	.....	
7209.44	5	1.454	3	6	4	4	4	.....	
7216.19	3	1.437	−2	3	3	2	3n	.....	Atm 6.54 in Arc.
7244.82	4	1.437	−1	4	5	3	2	.....	Atm 5.69 in Arc.
7251.74	4	1.424	−2N	3	5	3	.....	.....	
7253.76	1	.....	.....	.....	1	1n	.....	.....	
7299.67	2	1.424	cN	.....	4	2	.....	.....	
7308.18	1	.....	.....	.....	4	3	.....	.....	
7318.43	2	.....	.....	.....	.....	3	.....	.....	
7344.69	3	1.454	.....	.....	8	5	5	.....	
7357.73	3	1.437	−1	.....	5	2	2	.....	
7364.11	2	1.424	−2	.....	4	3	3	.....	
7366.58	1	1.424	.....	.....	3	3	3	1	*Fe* 6.41
7423.12	2	1.437	.....	.....	1on	6n	.....	.....	
7440.58	3	.....	.....	.....	5	4	2	.....	*Zr* 9.89
7474.93	1	1.741	.....	.....	2	1	1	.....	
7489.61	2	.....	.....	.....	2	2	1	.....	

Scandium (*21*).—The stellar line at 6604.27 A in Arcturus and Procyon is tentatively assigned to ionized scandium, 6604.609 A. The behavior of the observed line is satisfactory, since it is absent from Betelgeuze and Aldebaran.

Titanium (*22*).—The behavior of the titanium lines is shown in Table VIII. In general, their intensities increase in the cooler stars.

Bands of titanium oxide.—A number of *TiO* bands appear on the spectrograms of α Orionis and α Tauri. In the case of the former the three strong bands at 7054, 7087, and 7125 A are the most prominent features of this part of the spectrum.

The red infra-red system of *TiO* was recently discussed by N. T. Bobrovnikoff[14] for the star α_1 Herculis. This system, $^3\Sigma - {}^3\Pi$, has been measured in the laboratory by Miss Lowater[15] and by A. Christy.[16] Practically all of the bands found by Bobrovnikoff in α_1 Herculis are present, with about equal intensity in α Orionis. There is a definite weakening of these bands in α Tauri, as is to be expected.

In this study the plates were measured by setting the crosswire on the approximate center of the line. If there could be no question of the band nature, the setting was made on the head. In general, the measures give a wave-length a little high, since most of the bands appeared like diffuse lines.

The data for the *TiO* bands are assembled in tables according to sequence. The α_1 Herculis data are from Bobrovnikoff's paper. Laboratory figures are due to Miss Lowater.

There is no evidence for the presence of the *TiO* bands in Arcturus, type Ko. If they were present with Rowland intensity 1 or greater, they would doubtless have been detected. The absence of the three strongest *TiO* bands from the spectrum of Arcturus indicates definitely that any coincidences of measured lines in Arcturus with the weaker bands of *TiO* are accidental.

It appears that the bands of the red infra-red system of *TiO* first appear between Ko and K5. Hale and Adams[17] found the strongest band heads in the spectra of sun-spots. Their published illustration is quite convincing, especially for the band heads at 7054 A, 7088 A, and 7125 A. The sun-spot spectrum is usually considered to be of spectral class K2.

Professor A. Fowler[18] was the first to associate these bands in M-type stars with the bands of an oxide of titanium. In Richardson's

[14] *Ibid.*, **78**, 211, 1933.

[15] *Proc. of the Phys. Society*, **41**, 557, 1929.

[16] *Ap. J.*, **70**, 1, 1929.

[17] *Ibid.*, **25**, 75, 1907.

[18] *Proc. R. Soc., A*, **73**, 219, 1904; **79**, 509, 1907.

study of molecular spectra in sun-spots[19] he concludes that the *TiO* bands which he examined were present in the sun-spot spectrum and were probably absent from the disk spectrum. The bands which

TABLE IX

TiO BANDS, SEQUENCE +1

v′, v″	LABORATORY		α_1 HERCULIS	BETELGEUZE	ALDEBARAN	NOTES, BLENDS
	W.-L.	Int.				
	R-Heads					
a 1, 0	6651.5	5	3	5	2N	
b	6681.1	6	4	5N	3n	
c	6714.4	6	3	5	1n	
a 2, 1	6719.3	6	3	.....	.....	*
b	6747.8	5	2	3n	1n	
c	6781.9	5	6	10	1n	
a 3, 2	6785.8	4	6	8	2	*Fe* 3.72
b	6815.3	5	4	4	3	*Co* 4.97
c	6850.2	6	2	3n	2n	*Zr* 9.31; *Ni* 0.45
a 4, 3	6852.3	6	1	3n	2	
b	6883.8	3	.....	.....	.....	In B band
c	6919.5	4	3	.....	.....	In B band
b 5, 4	6951.5	.....	2	2	3	*Fe* 1.25
c	6988.6	1	3	4	1	*Fe* 8.54
	Q-Heads					
a 1, 0	6657.7	2	1	.....	.....	
b	6686.0	1	1	1	2n	†
b 2, 1	6724.0	5	1	.....	.....	

* Band masked by *Ca* 6717.8.

† Probably not due to *TiO* in Aldebaran.

he studied were 4954 A and 5167 A, members of the blue-green system $^3\Pi - {}^3\Pi$.[20]

The blue-green system and the red infra-red system have the same lower electronic level. It would be of interest to determine

[19] *Ap. J.*, **73**, 216, 1931.

[20] Cf. Christy, *Phys. Rev.*, **33**, 701, 1929.

TABLE X

TiO Bands, Sequence o

v′, v″	Laboratory W.-L.	Laboratory Int.	α_1 Herculis	Betelgeuze	Aldebaran	Notes, Blends
	R-Heads					
a o, o	7054.5	8	10	10	5n	
b	7087.9	12	10	10	5	
c	7125.6	14	10	10	6	Also *Ra* 1, 1
b 1, 1	7159.0	6	2	4N	.....	
c	7197.7	8	.....	4	2	*Ni* 7.02; also *Ra* 2, 2
b	7230.4	4	.....	.....	.....	
c	7269.05	6	.....	5	.....	Blend with *Qa* 3, 3 and *Qa* 2, 2; also *Ra* 3, 3
b 3, 3	7303.04	5	.....	4	3N	Atm 3.80
	Q-Heads					
a o, o	7060.0	3	2	2	2	*Ba* 9.94
b	7093.2	4	2	5n	1	
c	7131.3	5	2	4N	.....	Also *Qa* 1, 1; *Fe* 0.94
b 1, 1	7164.3	4	.....	1	2	*Fe* 4.45
c	7219.4	6	.....	1	1	
a 2, 2	7203.6	4	.....	1	.....	
c	7273.9	5	.....	5	.....	Also *Qa* 3, 3; blend with *TiO* 7269.05

TABLE XI

Unclassified *TiO* Bands

Laboratory W.-L.	Laboratory Int.	α_1 Herculis	Betelgeuze	Aldebaran	Blends, Notes
6626.08	2	2	6N	.....	*Fe* 5.05, *V* 4.85, *a*(9, 12) *Ra*
6634.30	2	2	3N	.....	Unclassified
7290.80	5	.....	5	3	Unclassified *Ni* 1.46
7297.01	3	.....	3	2	Unclassified

which of the two systems first appears along the stellar sequence. According to the Draper classification,[21] the blue-green system becomes faintly visible at K5. On our spectrograms of the K5 star α Tauri, the bands of the red infra-red system are quite strong and, although absent from Arcturus K0, might be anticipated at about K2.

Vanadium (*23*).—For three lines in this region vanadium seems to be unblended. There is a general tendency for the observed vanadium lines to increase in intensity, proceeding in the direction of the

TABLE XII

V I LINES, 6562–7593 A

LABORATORY			SUN		BETELGEUZE	ALDEBARAN	ARCTURUS	NOTES, BLENDS
Wave-Length	Int.	E.P.	Disk	Spot				
6565.85	2	1.178	−3	−1?	?	2	1	Betelgeuze, line at 6566.62, $i=2$
6578.97	.....	1.039	.....	−2	0	1	.....	
6605.93	5	1.190	2N	2	2	2	1	
6607.90	.....	1.345	.....	−1	1	1	.....	Blend *Fe* 6608.05
6624.84	5	1.213	3N	1	6N	4	3	*TiO*, 6626.08 in Bet. and Ald. *Fe* 6625.02
6753.02	.....	1.076	2N	.....	3	4	3	*Fe* 6752.72
6812.36	.....	1.039	−2N	.....	2	2	0	

cooler stars. Thus none of the lines listed in Table XII is visible in Procyon. In all cases the lines are stronger in Aldebaran than in Arcturus.

Chromium (*24*).—Chromium lines contribute to a number of blends. The three unblended lines listed in Table XIII show how rapidly the intensities increase in the cooler stars.

Manganese (*25*).—Although it is suspected that manganese may be a contributor in a few cases, there are no good identifications.

Iron (*26*).—Iron lines are fairly numerous in this part of the spectrum. About 150 lines are recorded, a number of which are unblended. Because of the wide range of excitation potential represented, the unblended lines were examined to note how the relative intensities of the lines in the four stars vary with the excitation potential.

[21] Cf., for instance, R. H. Curtiss, *Handbuch der Astrophysik*, 5, Part I, 47, 1932.

In Figure 2 the ordinates are differences in intensity on my scale, all reduced to zero for Arcturus. The general trend is for the high-

TABLE XIII

Cr I LINES

Sun			E.P.	Betelgeuze	Aldebaran	Arcturus	Procyon
Wave-Length	Disk	Spot					
6630.04.....	−2	4	1.026	1	1	1	.....
7355.89.....	1	5	2.877	5	3	3	1
7400.22.....	1	4	2.887	5	3	2	2n

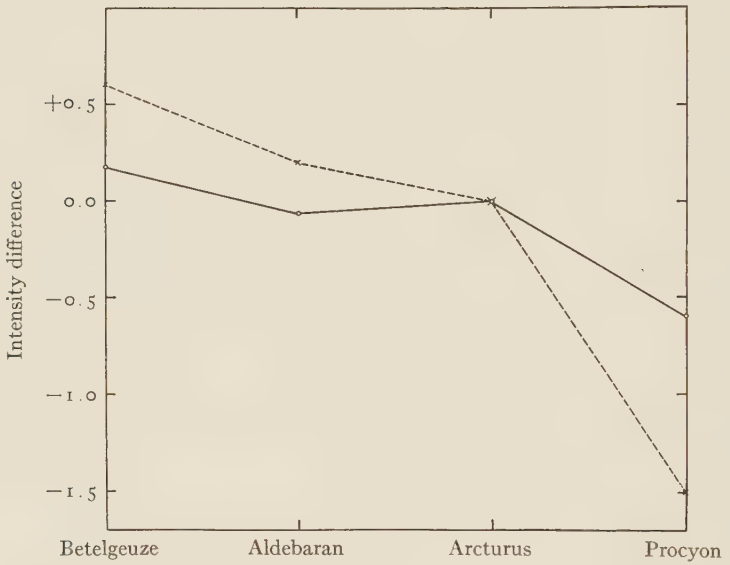

FIG. 2.—Comparison of iron lines of low and high excitation potentials. Dotted curve is based on twelve lines of average excitation potential 2.3 volts; solid curve on twenty-one lines of average excitation potential 4.4 volts.

excitation lines to be relatively stronger in Procyon than those of low excitation potential. The low-excitation lines are strengthened in Aldebaran and Betelgeuze relative to Arcturus and Procyon. The dotted curve is based on twelve lines whose average excitation po-

tential is 2.3 volts; the solid curve on twenty-one lines of average excitation potential 4.4 volts.

These stars cannot be considered homogeneous. For instance, between Betelgeuze and Procyon there is a difference in luminosity of

TABLE XIV

LINES OF *Zr* I

WAVE-LENGTH*	BETEL-GEUZE	ALDE-BARAN	ARC-TURUS	PRO-CYON	LABORATORY		SUN		C.	NOTES, BLENDS
					Int.	E.P.	Dk.	Sp.		
6603.27	3.11 1	.....	.....	.....	8	1.524	.....	.....	....	
6620.62	.....	0.56 1	.....	.....	5	2.313	.....	.....	....	
6752.73	3.22 3	3.00 4	2.94 3	.....	10	0.995	.....	....	B	*Fe* 2.73; *V* 3.02
6762.38	2.30 1	2.35 2	.....	.....	20	0.000	−2	....	A	*Cr* 2.42
6828.82	8.67 1	8.35 3n	8.45 1	8.37 2	10	1.390	.....	....	C	*Fe* 8.61
6832.93	2.85 3	2.87 4	.....	.....	12	0.070	.....	....	A	
6846.42	6.69 2	6.83 2	6.81 1	.....	5	0.620	.....	....	C	
6847.03					18	1.524	.....	....	A	
6849.29	0.21 3n	9.95 2n	.....	.....	8	1.524	−2N	....	C	*TiO* 0.23; *Ni* 0.45
6953.87	4.30 5n	5	.....	.....	20	0.648	.....	....	A	Atm 3.586
6966.49	6.59 3	6.04 3n	.....	.....	12	1.575	.....	....	B	
6990.86	0.49 4	0.44 1n	.....	.....	18	0.620	.....	....	B	
6994.38	4.56 3	4.63 2	.....	.....	12	0.684	−3	....	A	
7027.40	7.22 1	7.39 1	.....	.....	15	0.601	.....	....	A	
7087.35	7.15 10	7.88 5	.....	.....	20	0.601	.....	....	C	*TiO* 7.89
7094.61	5.18 3	5.40 1n	5.37 1	.....	7	1.524	.....	....	A	
7095.66					8	1.524				
7097.78	7.60 2	7.74 1	7.76 1	.....	25	0.684	.....	....	A	
7102.95	3.10 3n	3.32 4n	2.85 2n	.....	20	0.648	.....	....	A	
7103.77					18	0.000				
7111.71	1.47 4n	1.44 4n	1.14 2n	.....	12	0.517	.....	....	B	*Ni* 0.92; *Fe* 2.19
7169.14	Atm	9.02 3	.....	.....	40	0.620	.....	....	A	Atm 7170
7439.89	0.35 5	0.37 4	0.66 2	.....	20	0.540	.....	....	A	*Ti* 0.58; *Fe* 0.92

*Laboratory data from C. C. Kiess and H. K. Kiess, *Bur. of Stand. J. of Research*, 6, 621, 1934.

about 7 mag. Consequently, the difference of intensity of the iron lines of either group among the four stars is not significant. The point of interest is the behavior of the two groups, *inter se*.

Strontium (38).—The strongest line of *Sr* I in this region, 6617.28 A, is absent from all spectrograms.

Yttrium (39).—A line at 6793.65 A has intensities of 3, 3, and 2 in Betelgeuze, Aldebaran, and Arcturus, and has been identified as partially due to *Y* I 6793.64. The identification is not considered

very strong because the equally intense laboratory line at 6687.57 A is very doubtfully present in these stars. The strongest *Y* I line, at 6435.02 A, is out of the range of this study. It has a disk intensity of −3 and a spot intensity of 3.

Y II 6613.8 may contribute to the stellar line at 6613.79 A. *Y* II 6795.41 is not observed on my plates.

Zirconium (*40*).—Twenty-four laboratory lines have been attributed to neutral zirconium. In a large number of these lines zirconium is considered an "A" contributor. In the list are the two resonance lines 6762.38 A and 6832.93 A. The absence of the strong line 6769.16 A is unexplained. The lines become stronger from Arcturus to Betelgeuze, which is consistent with the fact that the lines are strengthened in the spot spectrum.

Only two weak ionized zirconium lines are recorded in the laboratory spectrum of this region, consequently no test can be made on the basis of the present study.

Barium (*56*).—At 7060 A is a stellar line to which *Ba* I 7059.94 A may contribute. In the case of Betelgeuze the close agreement in wave-length is fortuitous, since on the two plates of this star the determinations are 7059.60 A and 7060.24 A. This line is just to the red of the strong *TiO* band head at 7054 A and is consequently difficult to set on.

Lanthanum (*57*).—Ionized lanthanum is represented by a line at 7066 A. In Betelgeuze and Aldebaran the identification seems fairly probable.

ACKNOWLEDGMENTS

This study was made possible by the co-operation of the Yerkes and the Perkins Observatories. It is a pleasure to acknowledge my indebtedness to the officials of these two institutions. Dr. H. T. Stetson and Dr. N. T. Bobrovnikoff generously placed the equipment of the Perkins Observatory at my disposal. I have also profited by numerous discussions with Dr. Bobrovnikoff. The problem was suggested by Dr. Otto Struve, director of the Yerkes Observatory, and developed under his active encouragement. To him I am deeply grateful for granting to me the opportunity of carrying on this work.

YERKES OBSERVATORY
July 30, 1934